The Lunar Module Simulator: A Personal Account of Being an Instructor

BY A. A. JACKSON

The author was a member of the Flight Crew Training Division at the Manned Spacecraft Center in Houston, Texas, from January 1966 to September 1970. He worked in the simulator crew training branch. After initial assignments to the Gemini flight simulator and work on a fixed base simulator for the Lunar Landing Training Vehicle, he became the prime instructor for the Abort Guidance System on the Lunar Landing mission training simulator (LMS). Described are the factors needed for high-fidelity training crew stations, especially in the area of controls and displays; accurate simulation of the spacecraft systems, including the guidance computer and navigation system; complete visual display systems for simulated out-the-window scenes. An account is given of the author's experience with the installation and experience as an instructor on LMS. Some narrative of what the simulator did and instructor interaction with the Apollo LM crews is presented. The author includes some personal observations and a few anecdotes about Apollo crew training in this simulator.

Figure 1. Lunar Landing Research Vehicle at Edwards Air Force Base California. Credit: NASA

Introduction

In December of 1965, with coursework completed for a master's degree in physics and a looming draft notice, I was staring at an uncertain future. My mother spotted a small ad in the *Dallas Morning News*: NASA was hiring. With my lifelong interest in spaceflight—sparked years earlier by the *Collier's Magazine* series on space travel—it seemed worth a try.

What followed was a string of serendipitous events: a motel interview with Sam Nassiff, a rainy drive to Houston for a second interview with Stan Faber at the Manned Spacecraft Center (MSC, now known as the Johnson Space Center), and finally, an offer letter from NASA. I reported for duty in late January 1966, badge number blue-border (classified access), and a desk with only a phone.

It was my first real job.

My first assignment was on the Gemini Mission Simulator. It wasn't exactly thrilling—I had one button to push to simulate undocking the Gemini capsule from the Agena. But soon, a more engaging opportunity arose: working on a fixed base simulator for the Lunar Landing Training Vehicle (LLTV), at that time called the Lunar Landing Research Vehicle. A strange, skeletal machine flown in the crisp mornings over Edwards Air Force Base, it simulated lunar descent by compensating Earth's gravity with a gimbaled jet engine.

In the early 1960s, NASA felt training for the last 500 feet to landing by the Lunar Module (LM) would benefit from a 6-degree-of-freedom free flying vehicle. The vehicle was built by Bell Aerospace and tested at Edwards Air Force Base.

Five-sixths of the vehicle's weight is supported by a jet engine mounted vertically in a gimbal at the center of gravity of the vehicle. A system of gyros and hydraulic servos kept the jet engine essentially vertical with respect to the Earth, regardless of the vehicle's attitude. One-sixth of the vehicle weight was supported by a pair of rockets mounted on the main frame of the vehicle, one on either side of the jet engine.[1] The fixed base for the LLTV simulator was built mostly out of parts salvaged from other simulators at NASA centers, and it occupied a room in Building 4 at the Manned Spacecraft Center.

The Lunar Module Simulator

I was still a newcomer when I started exploring Building 5 at MSC after hours. One bay housed the Gemini simulator and another the Apollo Command Module Simulator, then under construction. The north bay, where the Lunar Module Simulator (LMS) would go, was then empty. Yet even climbing into the LM mock-up cockpit filled me with awe. I could hardly believe that I was this close to manned spaceflight.

In early 1967, I was assigned to be the prime instructor for the Abort Guidance System (AGS) on the LMS. AGS was a backup guidance system used if the Primary Guidance and Navigation Control System (PGNCS) failed during descent or ascent. Compact and advanced for its time, it relied on strapped-down sensors and a simpler interface—the DEDA (Data Entry and Display Assembly)—instead of a full keyboard.

AGS came into play in the vicinity of the Moon. When the LM and Command & Service Module (CSM) separated and the LM Primary Guidance Navigation and Control System (PGNCS) failed before or during powered descent, the AGS could be used for establishing a rendezvous. The tricky aborts took place during descent if the LM PGNCS failed; then the AGS had to do an "ascent" into a rendezvous orbit with the CSM. The other possibility was failure of the LM PGNCS before nominal ascent. Then the AGS would fly a nominal ascent and insertion in to a rendezvous orbit with the CSM.

The AGS was a pioneer in that it was the first "strapped-down" guidance system. The system used sensors fixed to the LM to determine motion, rather than a stable platform as in conventional inertial guidance systems. The entire system occupied only three cubic feet and consisted of three major components: (a) an Abort Electronic Assembly [AEA], which was the computer, (b) an Abort Sensor Assembly [ASA], which was the inertial state sensor, and (c) a Data Entry and Display Assembly [DEDA], which was a simple version of the data entry keyboard on the primary system.

The LMS used four Honeywell DDP-224 computers to simulate the LM's dynamic behavior. A 5-ton visual display system, including the impressive Lunar Surface Model and "star ball" for simulating celestial navigation, completed the simulator.

Once validated, the LMS became the center of Apollo LM mission training. From powered descent to rendezvous, from nominal landings to worst-case aborts, we covered every scenario. Crews trained obsessively. Neil Armstrong and Buzz Aldrin were especially methodical—quiet, focused, diligent. They'd fly a full rendezvous profile in total silence for hours. We once had to check on them to ensure they were still alive.

All Apollo LM crews came through our simulator: Conrad and Bean with their earthy Navy humor, Scott and Irwin, Mitchell and Shepard. Despite the long hours and technical headaches, the sense of mission never left us. We wrote thousands of Discrepancy Reports, fixed them, and kept the crews flying.

Training for a Mission to the Moon

Figure 2 shows the representation of an Apollo mission. Training had to prepare the crews for all phases of the mission. Important subsystems of the Apollo spacecraft and the milieu it operated in that needed to be simulated were: Guidance, Navigation, and Control, Radar, Propulsion, Reaction Control, Electrical Power, Environmental Control, Communications, Explosive Devices, Instrumentation.

The flight simulators must provide the crew with as close an approximation of spaceflight as is possible on Earth, without losing sight of the need to extensively practice procedures to respond to failures as well as nominal events. Requirements for realism increased the complexity of the simulation. For example, when an astronaut fires thrusters, the simulator must activate readouts and aural cues of the thrusters firing, fuel reducing, velocity changes, and also show movement in the scene outside the cabin window.

Mercury and Gemini mission simulators provided the base experience for the Apollo simulators. The complexity of the Apollo missions generated 11 simulators. The main ones were the fixed base Command Module Simulator for the Command and Service Modules, and the Lunar Module Simulator. Also, there were moving base and part task simulators. These simulators could run stand alone, in combined simulations of the CSM and LM, and for integrated simulations with Mission Control.

The focus here is on the Lunar Module and its mission. The main simulator training tasks were: undocking from the CSM, configuring to perform lunar descent, lunar landing, lunar ascent, and rendezvous and docking with the CSM. Main contingency events included abort from descent due to a possible failure of the Descent Engine, failure of the PGNCS during descent, possible partial failure of RCS during descent, possible failure of the PGNCS before ascent, or failure of PGNCS during Rendezvous. Figure 2 shows an abort from lunar descent due to some system failure.

The LMS was built by the Link Group of Singer-General Precision Systems Inc., under subcontract to Grumman Aircraft Engineering Corporation, with the Farrand Optical Company providing the visual display units. Singer produced two Lunar Module Simulators, one at the Manned Spacecraft Center in Houston and the other at Kennedy Space Center in Florida.

The components of the LMS consisted of a high-fidelity cockpit without the window displays, film projection equipment, a lunar surface model (for the last 8,000 feet of the descent trajectory), an instructor's console, and a computer complex of DDP-224 machines for vehicle dynamics and simulation of the guidance, navigation and control and the support equipment.[2]

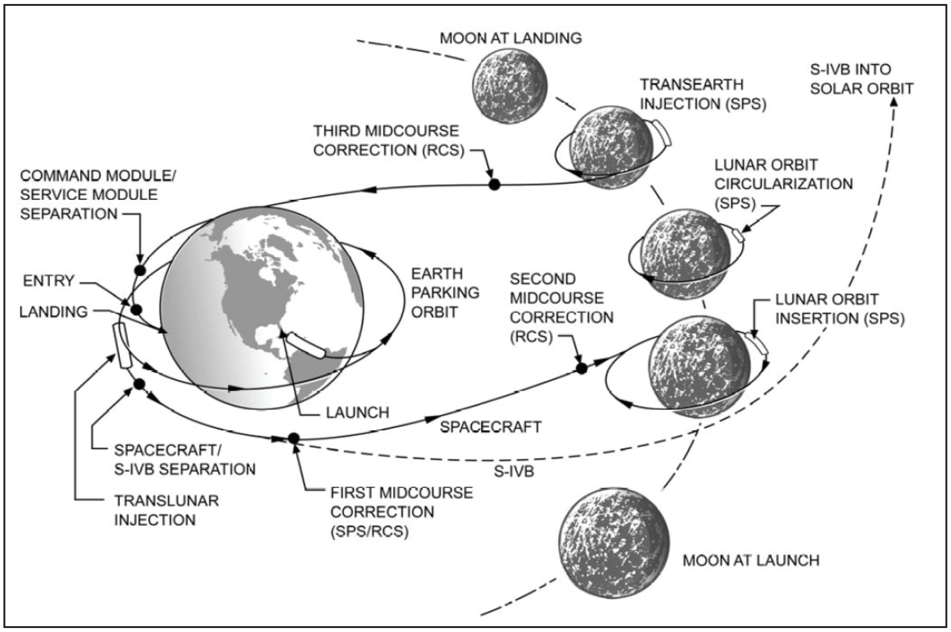


Figure 2. Nominal Apollo Mission. Credit: NASA

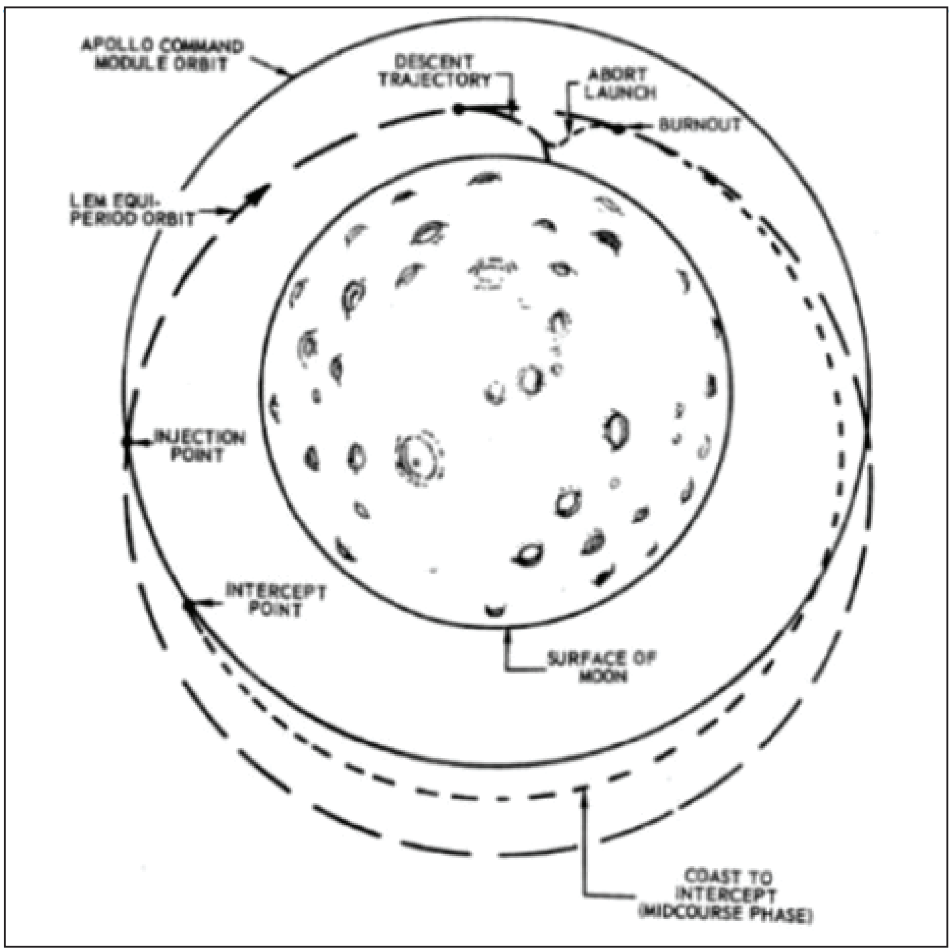


Figure 3. Off nominal LM descent with a failure. Abort to rendezvous.. Credit: NASA

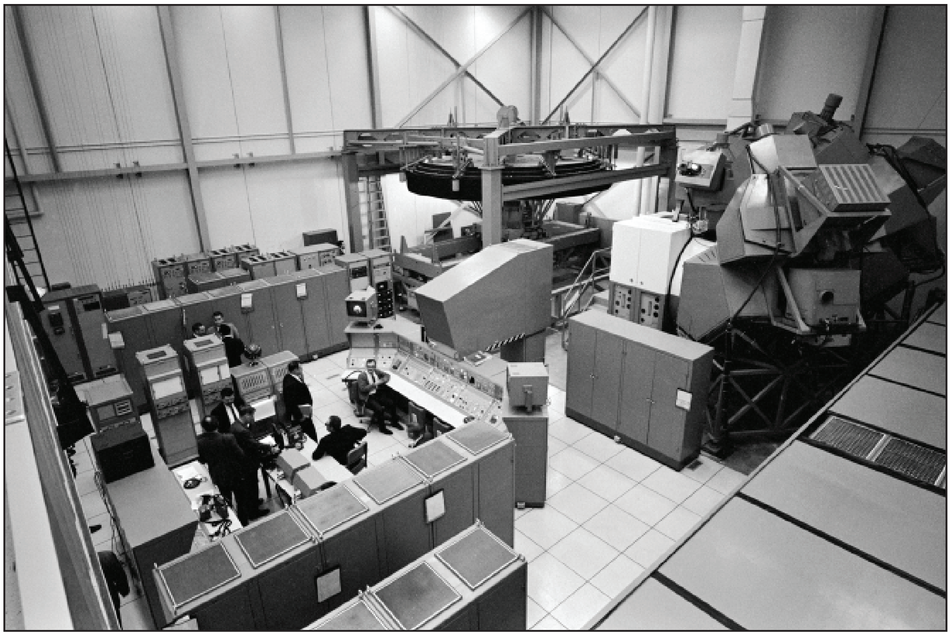


Figure 4. Lunar Module Simulator in Building 5 MSC, showing instructors station, LM cockpit (with projection equipment), the Lunar Surface Model and support equipment. To the left is a wall behind which is a room with the four Honeywell DDP-224 computers that drove the simulation. Much of the peripheral equipment shown was for interfacing and digital to analog conversion. Courtesy: AA Jackson

Fig. 5. Apollo simulators star ball. Courtesy: AA Jackson

Two Difficult LMS Components.

In the real LM there are three windows— one overhead, and two forward. The simulator windows had to display a star field, the Earth's surface for *Apollo 9*, and the lunar surface from 113 km down to the surface, accurate out the front windows from 5,000 meters to lunar surface touchdown, precise as possible, sky location of navigation stars, and the CSM during rendezvous and docking operations. These turned out to be very difficult tasks to simulate.

A combination of display techniques: film, optics, models, and TV in appropriate combinations was used for display the surfaces of the Earth's and the Moon. Simulation of the star field for use with the Alignment Optical Telescope in the LM was done with a "star ball" and associated optical equipment. This was important training for interfacing with Inertial Measurement Unit for the Guidance and Navigation system. Star measurements were made to provide an inertial coordinate system for the PGNCS.

The star fields displayed in the Apollo simulator windows were produced with specially constructed spheres (Figure 5). This sphere is one of the larger ones, with a radius of 13.58 inches, along with its positioning drives, from one of the Apollo simulators operated during the program. Situated on the sphere are 998 model stars up to and including stars of the fifth magnitude. The simulated stars are reflective ball bearings tinted to present the correct spectral characteristics and mounted on a black surface. When illuminated, the balls produced a star-like spot of light, which was projected as background into the Command and Lunar Module simulator's crew compartment windows by an array of windows and mirrors.[3] Also, the crews could see the stars in the Alignment Optical Telescope.

For LM descent to the Lunar surface, a set of different altitude scales was created using film. For the last 8,000 feet the lunar surface was projected to the LM windows using a large-scale model of the landing site. This was a large piece of equipment using a TV camera that had six degrees of freedom and a model of the lunar surface. The Houston simulator utilized the *Apollo 11* landing site, while the Kennedy Space Center installed mission specific landing sites, because the detailed lunar mission-specific surface models were expensive to make. The crews spent the last two months or so at the Kennedy Space Center before a mission. At KSC they would practice the mission procedures and wearing their space suits.

The flight crews were hands-on thousands of times, during a mission, with the Primary Guidance Navigation and Control computer, its keyboard and displays.

All the functions in Figure 7 had to be modeled in the simulations, including all translational and rotational degrees of freedom, and the dynamical forces generated by the descent and ascent engines plus the actions of the rotational control system. This was done with functional math models programmed in DDP-224 Assembly Language. However, for the Primary Guidance, Navigation and Control, the functional modeling proved to be quite expensive and too time consuming. This presented a serious problem.

In the place of functional simulations, a computer running MIT's GN&C computer's code using an interpretive simulation was implemented. This model took an instruction from the MIT program, executing it using as many instructions as necessary from its own repertoire, using DDP-224 computers. MIT sent Apollo's primary GN&C computer program to MSC where it was run in both the CMS and LMS. This interpretative simulation had the additional benefit of serving as another check on the Apollo MIT navigation software.

Development of the LM Simulator

We LMS instructors spent the first half of 1967 reading the documentation on the Lunar Module. Various sources, mainly Grumman, published a vast number of documents on requirements and operation of the vehicle, as well as mission procedures. A few months of reading all those will hold you a lifetime. (It was interesting that the LM was originally called the Lunar Excursion Module. Someone in Washington, DC didn't like "Excursion" in the name and it got dropped so the vehicle became just the Lunar Module).

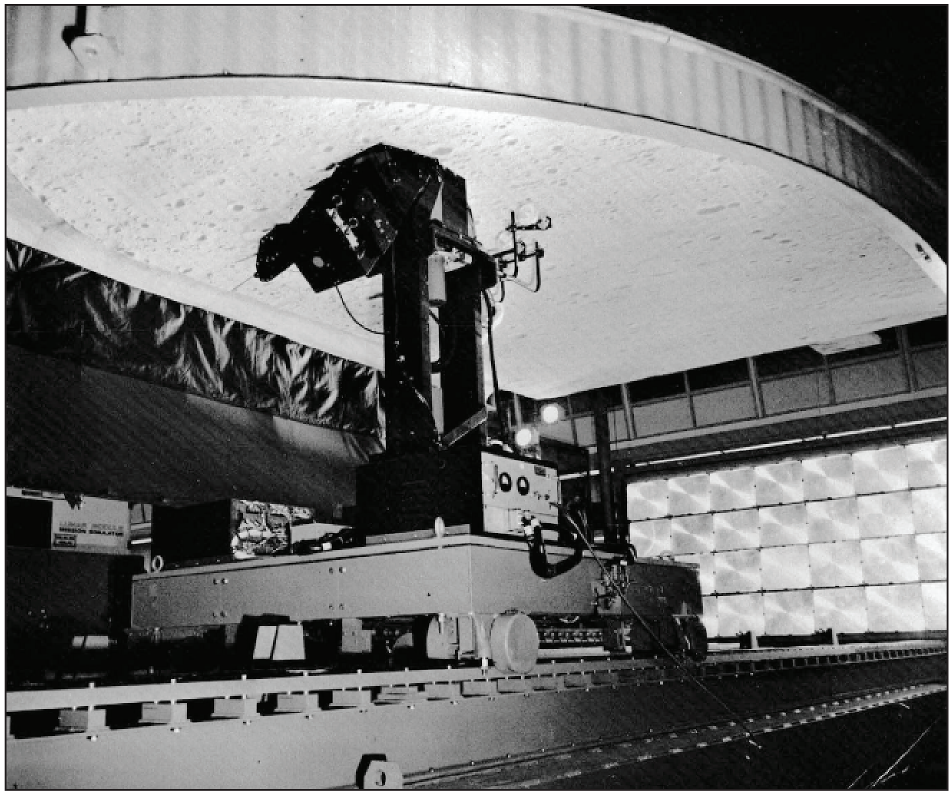


Figure 6. Lunar Surface image generator. Courtesy: AA Jackson

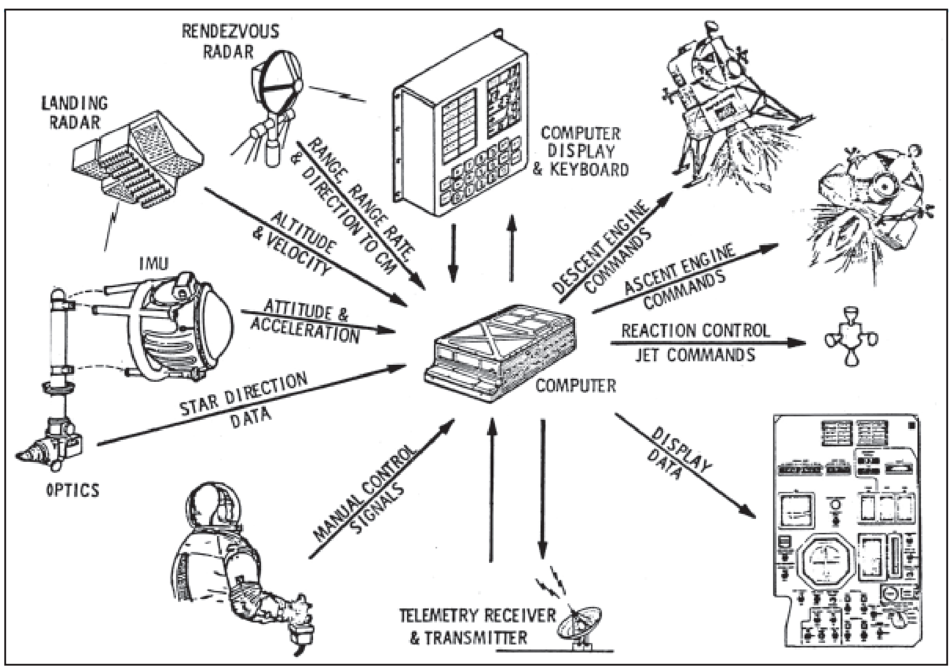


Fig. 7. Guidance, Navigation and Control of the LM Credit: NASA

The main components of the LMS arrived in Houston early fall of 1967. Link had become Singer-Link by then and the technicians spent about two months assembling the complex, which consisted of the cockpit,

Figure 8. Neil Armstrong and Buzz Aldrin in the Lunar Module Simulator at the MSC
Credit: NASA

instructor's console, projectors and four DDP-224 computers. There was five tons of visual display equipment with the huge Lunar Surface image generator (Figure 6), accounting for a major portion of that weight.

Bringing up the simulator math model and the interconnections, especially the digital to analog conversion interface took about three months. Validating the simulation took many months. The crews were very eager to get into the cockpit of the LMS, so we started early simulations with a lot of problems to work out. I began to work an 'irregular' shift, weekday's eight to noon in crew training, back at 6 pm to midnight for LMS validation. Later I worked some midnight to 5 a.m. shifts then back in the afternoons for crew training. Weekend work was usually on Sundays so I could take Saturday off.

We found a lot of errors in the simulation and many Discrepancy Reports were written. I will note one funny one. The first mission we supported was *Apollo 9*, which was an Earth orbit rendezvous practice mission with the CSM and LM. The lunar mission crews wanted to try the mission procedures being generated by the Mission Planning and Analysis Division (see Appendix C) and the Procedures Section in our division. For some reason ascents from the lunar surface were tried first. Everything from 30 minutes before liftoff went smoothly but after liftoff the LM ascent engine would burn and burn, until it ran out of fuel, and then the LM vehicle would go into a ballistic arc and crash into the Moon! It took about a day for us to figure it out, because the *Apollo 9* training the gravitation constant in the LM simulation was the Earth's and not the Moon's!

The AGS simulation required functional fidelity to a fault. Another memorable bug during *Apollo 9* training saw the LM crash on every ascent—because someone had left Earth's gravity value in the lunar simulation model. The simulator was complex; getting it to behave as expected was sometimes more of an art than a science.

In early 1968 we were finally ready for crew training. We prepared overhead presentations as introductions, but the crews quickly nixed those because they wanted to get their hands on the hardware and fly.

The Apollo crews already had an uncountable number of hours of familiarization with the spacecraft hardware and part task simulators at other NASA centers. Over the Apollo mission training span, the flight crews spent nearly 25,000 hours in the fixed base CM and LM simulators at the MSC and KSC. The general order of training was to spend a large portion of initial training at MSC and about the two final months before a mission training at KSC. Time in the simulators at MSC was spent on procedures, and on testing changes to flight software and some modifications to cockpit hardware interfaces.

Apollo 11 and *Apollo 12* training

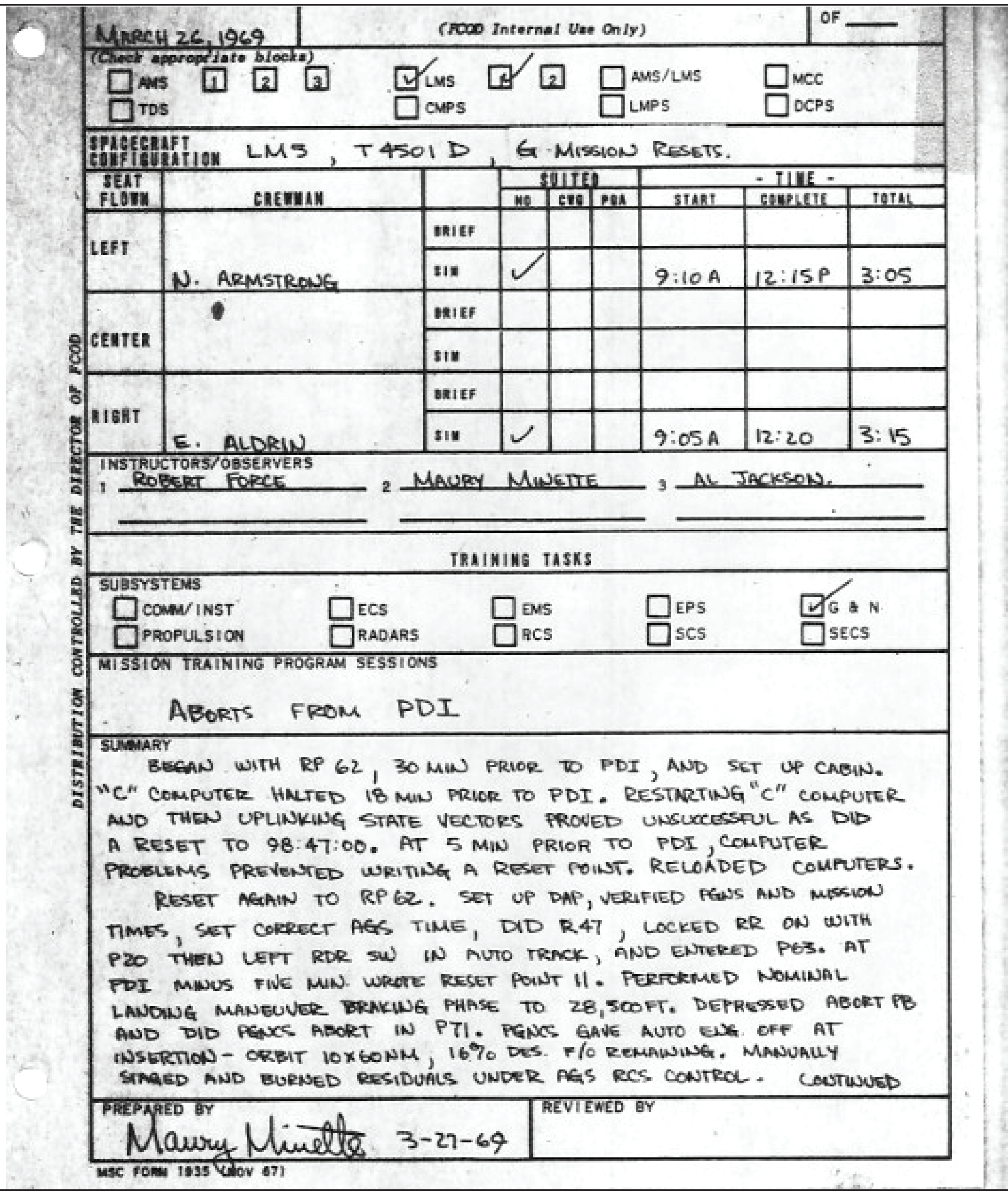
The LM crews we saw the most of, in Houston during 1968 and 1969, were Pete Conrad and Alan Bean, and Neil Armstrong and Buzz Aldrin. From 1968 to 1970, I worked with every Apollo crew. All were skilled and capable; to me I was impressed by their sense of humor. That varied in expression from Neil and Buzz's dry humor to the blue language of old Navy men like Conrad and Bean. I remember once when Conrad and Bean were practicing a powered descent, Bean asked Conrad what he would do if the Descent Engine failed and they could not abort. Conrad said "I would get up right close to the cockpit window to see what the lunar surface was like as it came up."

My most vivid memory is of the *Apollo 11* crew. Neil and Buzz seemed to be in the simulator every workday. Sometime Buzz came in by himself before Neil arrived.

To me Neil and Buzz were the most diligent. They were the quietest in the cockpit. One time they came in at 8 a.m. and worked on a rendezvous, not saying a word to one another for three hours! We were sure they were okay, but about 11 a.m. one of the instructors said, "Maybe we should go up to the cockpit and see if they were alright".

Figure 9 shows a training report from 27 March 1969 with Armstrong and Aldrin in the LMS cockpit. "G Mission" was the generic name for a lunar landing. Note this session was after *Apollo 8* and *9* had flown, but we were still using the"'A to G" generic mission designations.

PDI is Powered Descent Initiation. In the simulator, we flew a lot of aborts; the profile shown here is similar to that in Figure 2.


MARCH 26, 1969 — (FCOD Internal Use Only) — OF ____

(Check appropriate blocks)

☐ AMS ☐ 1 ☐ 2 ☐ 3 ☑ LMS ☑ 1 ☐ 2 ☐ AMS/LMS ☐ MCC

☐ TDS ☐ CMPS ☐ LMPS ☐ DCPS

SPACECRAFT CONFIGURATION: LMS, T4501 D, G MISSION RESETS.

SEAT FLOWN	CREWMAN		SUITED NO	SUITED CWG	SUITED PGA	TIME START	TIME COMPLETE	TIME TOTAL
LEFT	N. ARMSTRONG	BRIEF						
		SIM	✓			9:10 A	12:15 P	3:05
CENTER		BRIEF						
		SIM						
RIGHT	E. ALDRIN	BRIEF						
		SIM	✓			9:05 A	12:20	3:15

INSTRUCTORS/OBSERVERS

1 ROBERT FORCE 2 MAURY MINETTE 3 AL JACKSON.

TRAINING TASKS

SUBSYSTEMS

☐ COMM/INST ☐ ECS ☐ EMS ☐ EPS ☑ G & N

☐ PROPULSION ☐ RADARS ☐ RCS ☐ SCS ☐ SECS

MISSION TRAINING PROGRAM SESSIONS

ABORTS FROM PDI

SUMMARY

BEGAN WITH RP 62, 30 MIN PRIOR TO PDI, AND SET UP CABIN. "C" COMPUTER HALTED 18 MIN PRIOR TO PDI. RESTARTING "C" COMPUTER AND THEN UPLINKING STATE VECTORS PROVED UNSUCCESSFUL AS DID A RESET TO 98:47:00. AT 5 MIN PRIOR TO PDI, COMPUTER PROBLEMS PREVENTED WRITING A RESET POINT. RELOADED COMPUTERS.

RESET AGAIN TO RP 62. SET UP DAP, VERIFIED PGNS AND MISSION TIMES, SET CORRECT AGS TIME, DID R47, LOCKED RR ON WITH P20 THEN LEFT RDR SW IN AUTO TRACK, AND ENTERED P63. AT PDI MINUS FIVE MIN. WROTE RESET POINT 11. PERFORMED NOMINAL LANDING MANEUVER BRAKING PHASE TO 28,500 FT. DEPRESSED ABORT PB AND DID PGNCS ABORT IN PTI. PGNCS GAVE AUTO ENG. OFF AT INSERTION - ORBIT 10X60NM, 16% DES. F/O REMAINING. MANUALLY STAGED AND BURNED RESIDUALS UNDER AGS RCS CONTROL. CONTINUED

PREPARED BY Maury Minette 3-27-69 — REVIEWED BY

MSC FORM 1935 (NOV 67)

DISTRIBUTION CONTROLLED BY THE DIRECTOR OF FCOD

Figure 9. LMS training report from March of 1969

Courtesy: AA JACKSON

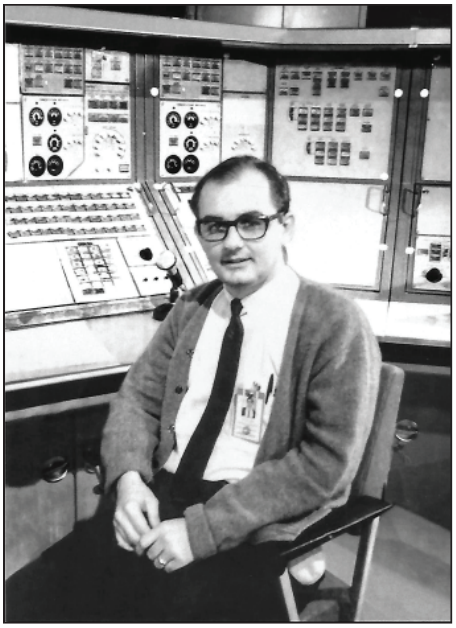


Figure 10. The author at the "AGS" station, LMS MSC Houston, Texas 1969.
Courtesy: AA JACKSON

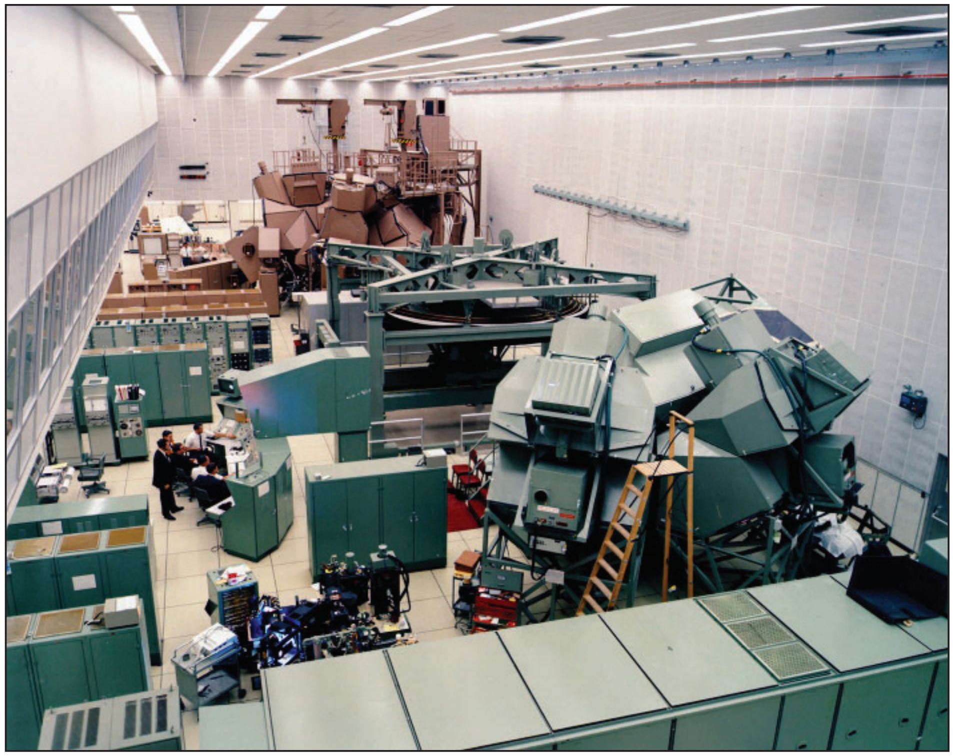


Figure 11. The Apollo Simulator Complex at KSC. Courtesy:AA Jackson

The narrative shows the difficulties we still had in setting up simulations. RP 62 refers to "reset point," which was a collection of digital data on tape denoting the LM state vector, equations of motion state and vehicle instrumentation setup state. The "C" computer was one of the DDP- 224s. The crew had to exercise both the Primary Guidance Navigation and Control System as well as the Abort Guidance System in this exercise to check out procedures for missions. These kinds of sessions were performed after nominal descent; ascent and rendezvous operations had been completed. There were a lot of glitches in the simulator that were solved so that when the crews went to KSC the mission training was smoother.

A funny incident occurred during a training session once when the lunar surface model was up and running. Neil and Buzz had done a nominal descent and landing. Usually, the nominal view out the LM window was the landing site. However, some technician had attached a little plastic bug in view of the camera system that transmitted the image to the crew. Armstrong went along with the joke and reported a 200-foot-high bug was in view on the lunar surface. Then he said the egress to the lunar surface would have to be canceled. We asked why, he said he was not afraid of the bug, but that the 10,000-foot being that had placed it there was an unknown he was not willing to deal with.

One of the more unusual training exercises was LM manual ascent. If the primary and back up guidance and navigation systems failed it was possible to make a hands-on ascent to lunar orbit. Conrad and Bean practiced this in the LMS many times.

Another thing I vividly remember during those days. The DDP-224s and all the attendant electrical equipment generated a large amount of heat. The air conditioning in Building 5 had to be turned down to about 50 degrees Fahrenheit. We turned into popsicles. In the summer, in Houston, it gets hot, very hot, after working in the simulator. I could leave work, go to my car, and drive all the way home with the windows up and the air conditioning off.

As much as we saw of the crews we never socialized with them. All our interactions with them were purely business. Once a small group of us did take a trip with the *Apollo 11* crew to TRW at Redondo Beach in California for a technical briefing in late 1968 or early 1969 (I can't remember exactly). A meeting was held in a big briefing room with a lot of technical people from TRW, and I remember an interesting incident. A question came up about terminal phase rendezvous. I thought for sure Aldrin would get up to give a chalk talk but it was Armstrong who went to the board and gave the technical talk. Neil and Buzz were our most "academic" astronauts.

We instructors were not surprised that Neil and Buzz became the first to land on the Moon; it could have been Conrad and Bean. According to Andrew Chaikin it was just by chance.[4]

Conclusion

I became totally addicted to spaceflight in the early 1950s, mostly due to the *Collier's Magazine* series on human space flight 1952 to 1954. Thought I would be an engineer but got a bachelor's degree in mathematics and a master's degree in physics, later a PhD in physics. To my surprise NASA was formed and manned spaceflight began in the early 1960s. It still feels like a happy chance that I wound up, at just the right time, to participate in the Apollo program. I never expected to get that close to manned space flight. I was a math and physics guy, not a pilot or engineer.

After Apollo, I continued in aerospace for 45 years. But nothing matched those first, intense years: building a successful training simulator, the weight of training men who'd go to the Moon, the surreal pride of seeing Armstrong and Aldrin descend onto Tranquility Base, remembering they'd trained in our cockpit.

Acknowledgement

I thank a fellow Apollo instructor, Frank Hughes, who was at KSC, for reference materials.

Appendix A (Apollo Simulators at KSC)

Figure 11 shows the Apollo training simulators at Kennedy Space Center (KSC.) The brown assembly in the distance is the Command Module Simulator, the green one in the foreground is the Lunar Module Simulator. This photo was taken from atop a Command Module Simulator there were two CMSs at the Cape.

One of the lunar surface models for the LMS was at the Cape. In Houston we kept a model similar to the *Apollo 11* landing site, but at KSC they used models specific to the mission.

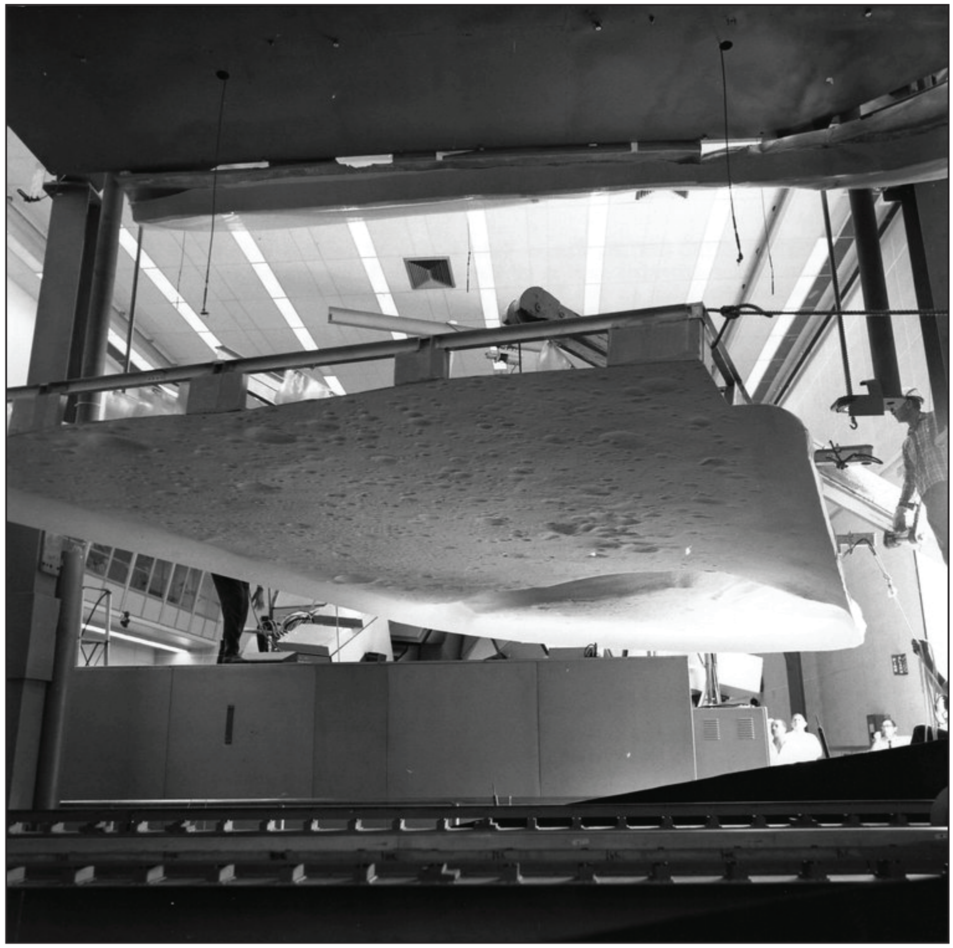


Figure 12. Lunar surface model at KSC. This may be for *Apollo 14*.
Courtesy: AA Jackson

Appendix B (Lunar Module Forward Cockpit)

See Figure 13. Lunar Module Forward Cockpit.

Appendix C (Mission Planning and Analysis Division)

In most accounts of the Apollo program, Mission Operations Directorate (MOD) gets most mention because Mission Control got the most coverage. I point out Mission Planning and Analysis Division (MPAD) for special consideration. What MPAD did was very important with regards to mission planning. All mission phases that defined guidance, navigation and control and astronaut procedures originated from detailed analysis in MPAD. From 1963 to 1969 MPAD provided the framework for most the ground and flight software used during Apollo.[5]

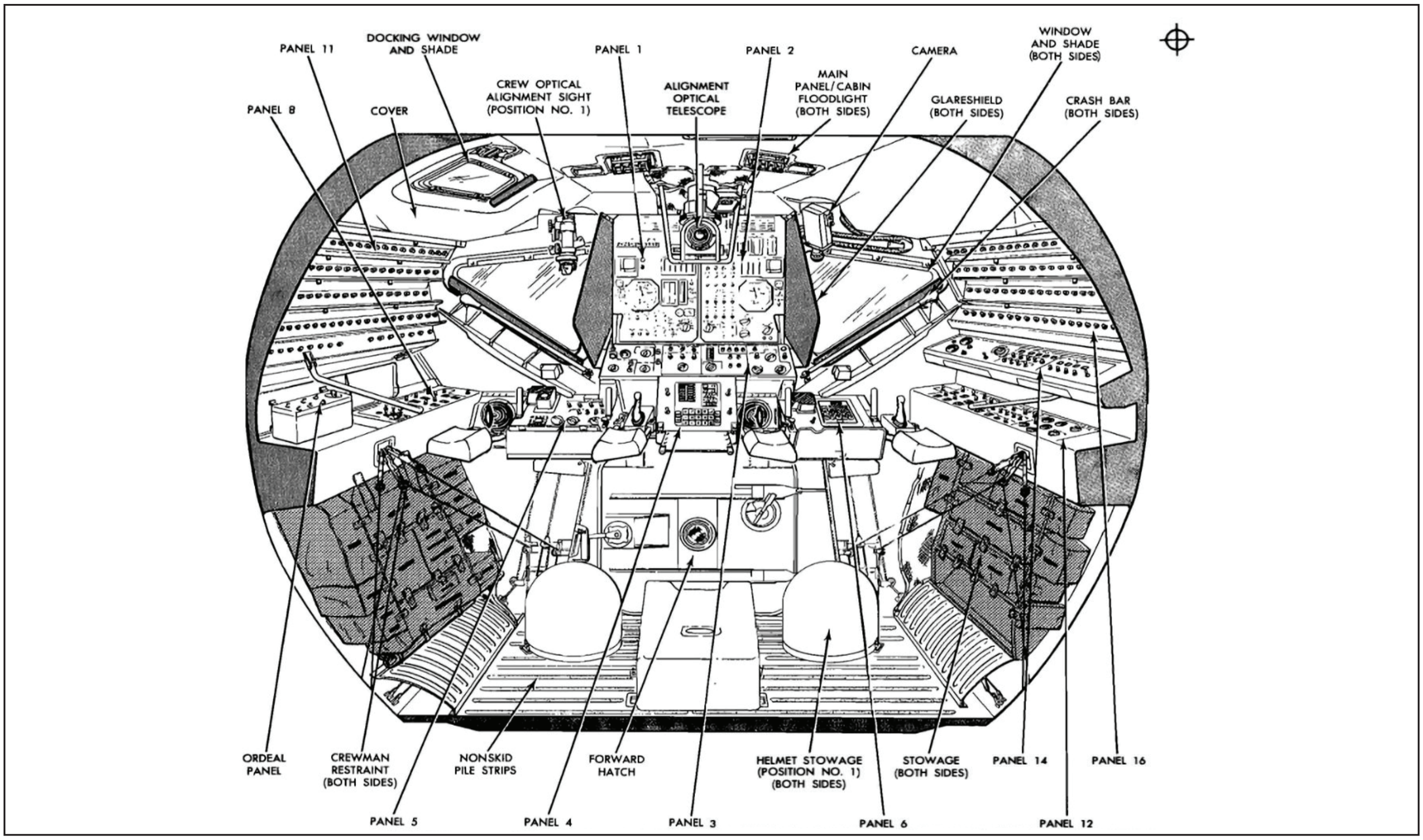


Figure 13. Lunar Module Forward Cockpit. Courtesy: TEXT

About the Author

AA Jackson was a member of the Flight Crew Training Division at the Manned Spacecraft Center in Houston, Texas, from January 1966 to September 1970. He worked in the simulator crew training branch. After initial assignments to the Gemini flight simulator and work on a fixed base simulator for the Lunar Landing Training Vehicle, he became the prime instructor for the Abort Guidance System on the Lunar Landing mission training simulator.

Notes

1 Nassiff, S., Armstrong, N., "Apollo Flightcrew Training Lunar Landing Simulators," AIAA Paper N. 68-254, March 1968.

2 Woodling et al., *Apollo Experience Report. Simulation of Manned Space Flight for Crew Training*, NASA MSC-07036, 1972; Stanley Faber oral history interview, NASA Oral History Project, Houston, Texas—8 May 2002, https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/FaberS/FaberS_5-8-02.htm; Carroll H. "Pete" Woodling oral history interview, NASA Oral History Project, Houston, Texas—19th January 2000, https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/WoodlingCH/WoodlingCH_1-19-00.htm

3 Brown, M. Waters, J. "The Lunar Module Simulator," *Simulation*, vol 15, 1, 27-29, July 1970.

4 Chaikin, Andrew, *A Man on the Moon: The Triumphant Story of The Apollo Space Program*, Penguin Group, 1994, 137.

5 NASA-TM-X-58006, *Proceedings of the Apollo Lunar Landing Mission Symposium*, NASA, 662 pages.